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VIRUS REMOVAL DURING CONVENTIONAL DRINKING WATER TREATMENT

by

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FOREWORD

The many benefits of our modern, developing, industrial society are accompanied by certain hazards. Careful assessment of the relative risk of existing and new man-made environmental hazards is necessary for the establishment of sound regulatory policy. These regulations serve to enhance the quality of our environment in order to promote the public health and welfare and the productive capacity of our Nation's population.

The complexities of environmental problems originate in the deep interdependent relationships between the various physical and biological segments of man's natural and social world. Solutions to these environmental problems require an integrated program of research and development using input from a number of disciplines. The Health Effects Research Laboratory, Research Triangle Park, NC and Cincinnati, OH, conducts a coordinated environmental health research program in toxicology, epidemiology, and clinical studies using human volunteer subjects. Wide ranges of pollutants known or suspected to cause health problems are studied. The research focuses on air pollutants, water pollutants, toxic substances, hazardous wastes, pesticides, and nonionizing radiation. The laboratory participates in the development and revision of air and water quality criteria and health assessment documents on pollutants for which regulatory actions are being considered. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of environmental regulatory decisions involving the protection of the health and welfare of all U.S. inhabitants.

This report describes enteric virus findings in treated drinking water relative to water quality indicators. Work of this type helps to provide a data base for evaluating the adequacy of current drinking water standards in preventing waterborne infectious disease. Field study sites in other countries can provide the opportunity to investigate situations that may not now occur in the United States, but could occur if certain trends or policies are adopted. They may also help to evaluate the "margin of safety" that exists in current U.S. drinking water conditions, thereby, providing valuable preventive health information.

F. Gordon Hueter, Ph.D.
Director
Health Effects Research Laboratory

ABSTRACT

The reduction of enteroviruses and rotaviruses was studied at full scale 205 mgd water treatment plant involving chemical clarification, sand filtration and chlorination. Reduction of enteroviruses and rotaviruses averaged 81% and 93%, respectively, for the complete treatment process. The greatest reduction of enteroviruses occurred during pre-chlorination/flocculation and filtration, while a significant reduction of rotaviruses occurred during pre-chlorination/flocculation and final chlorination. Enteroviruses or rotaviruses occurred in 24% of the finished water samples containing chlorine levels of > 0.2 mg/L, and meeting coliform bacteria (1/100 ml) and turbidity (1 NTU) standards. The results of this study indicate that finished water having measurable levels of free residual chlorine and meeting standards for coliform bacteria, and turbidity cannot be assumed to be virus free.

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SECTION 1

INTRODUCTION

PROJECT OBJECTIVES

The isolation of viruses from treated drinking water (Committee 1979; Payment, 1981; Melnick and Gerba, 1982; Sekla et al., 1984; Payment and Trudel, 1984) has raised concerns that water treatment methods may not always adequately insure the removal of viruses from water designated for human consumption. In fact, viruses have been isolated from drinking water that met recommended levels of coliform bacteria, chlorine and turbidity (Deetz et al., 1984; Payment and Trudel, 1984). The question is raised as to whether or not current drinking water standards ensure safe drinking water. In a previous report (Deetz et al., 1984), we described the isolation of enteroviruses and rotaviruses from treated drinking water in a distribution system and at a water treatment plant. This study reports the results of a more extensive investigation at the same site on the removal of naturally occurring viruses by water treatment processes including pre-chlorination/clarification, filtration, and chlorination at a full-scale water treatment plant.

IMPORTANCE OF PROBLEM AND REVIEW OF PREVIOUS WORK

During the last decade there has been increasing attention paid to the contamination of water and soil by human enteric viruses. As noted in a recent report by a World Health Organization Study Group on the problem of

viruses in water (WHO, 1979), the problem is not fully appreciated by the medical and public health profession. Since the turn of the century, it has been well known that there is a significant risk of contracting infectious disease from the ingestion of sewage-contaminated water and food. The spread of enteric bacterial disease by this route has been well controlled by the widespread application of bacterial standards and modern treatment processes for drinking water and sewage. Enteric viruses have been shown to be less effectively removed or inactivated than indicator bacteria by many treatment processes, principally in laboratory studies. This fact had often raised serious questions about the adequacy of bacterial standards in judging the sanitary quality of water as related to its potential for the transmission of viral disease. These questions led the World Health Organization (WHO, 1979), among others (Sproul, 1983), to recommend under certain circumstances the monitoring of and the adoption of viral standards for drinking and other types of water.

Enteric viruses have been isolated from treated drinking water supplies (Melnick and Gerba, 1982; Payment, 1981; Sekla et al., 1980), but few of these studies were designed to quantitatively evaluate the treatment processes. Often little information is contained in the literature on the various aspects of the water treatment process involved and the bacterial and chemical water quality. Without such information, it is difficult to determine the adequacy of the water treatment. A number of factors which should be considered when examining data from previous studies include recognition of the following facts: (1) Most of the earlier studies were not quantitative and some were limited to the sampling of relatively small volumes of water. (2) None of the methods used to concentrate viruses from water were 100% efficient in recovering all of the viruses present. In

laboratory studies, many of the methods will achieve efficiencies of 50% or more, but since concentration methodology is greatly affected by water quality, such efficiencies are probably not achieved under field conditions. (3) Methods used for concentration of viruses were usually optimized for enteroviruses, which constitute only one genus among the enteric viruses. Methods were not available in earlier studies for the detection of rotaviruses, Norwalk virus, adenoviruses, etc. (4) Most of the investigators used tissue culture techniques that limited isolation primarily to the enteroviruses.

The majority of processes used to treat sources of potable water are capable of reducing virus numbers. However, much of the available information on the removal of enteric viruses by water treatment processes is based on laboratory studies with members of the enterovirus group (particularly, poliovirus type 1) and a few selected coliphages.

Few studies have been done on the removal of naturally-occurring enteroviruses by drinking water treatment plants under field conditions. Such information is very important since not all enteric viruses are likely to be removed with equal and high efficiency by a given water treatment process. For example, laboratory studies have shown poliovirus is more effectively removed from water by alum flocculation and from sewage by adsorption to sludge flocs than rotavirus (Farrah et al., 1978). Likewise, under field conditions at an activated sludge sewage treatment plant, enteroviruses appeared to be more effectively removed than were rotaviruses (Smith and Gerba, 1982). It is also recognized that naturally occurring viruses may be more resistant to chlorination than prototype laboratory strains (Shaffer, 1978).

SECTION 2

CONCLUSIONS

1. Both enteroviruses and rotaviruses could be isolated from finished drinking water containing free chlorine levels of >0.2 mg/L, and meeting coliform bacteria (1/100 ml) and turbidity (1 NTU) standards.
2. Both enterovirus and rotavirus reduction averaged 81% and 93%, respectively, for the complete treatment process involving flocculation, sand filtration, and chlorination.
3. Reduction of enteroviruses was greatest during pre-chlorination/clarification and sand filtration. The greatest reduction of rotaviruses occurred during pre-chlorination/clarification and post-chlorination of the finished water.
4. The complete water treatment process was more effective in the reduction of turbidity, coliform, fecal coliform, fecal streptococci, standard plate count bacteria, and coliphage than of enteric viruses.
5. The numbers of standard plate count bacteria and coliphage were positively correlated to the presence of enteroviruses in the raw water while coliphage counts were positively correlated to the presence of rotaviruses in the finished water.

SECTION 3

RECOMMENDATIONS

1. Studies should be conducted to determine the efficiency of human rotavirus removal by drinking water treatment processes.
2. Better methods should be developed for the detection and concentration of coliphage from water.
3. Longer term studies should be made of the occurrence of enteroviruses and rotaviruses in treated drinking water taking advantage of the continual development of detection methods. This would allow the development of a larger data base which could be used to determine if stronger correlations exist between the presence of coliphage, total plate count bacteria and enteric viruses.
4. Research should be conducted on water quality and operational treatment conditions that will to assure essentially complete removal of viruses.

SECTION 4

MATERIALS AND METHODS

WATER TREATMENT PLANT

A 205 mgd water treatment plant was selected for study based on previous results which indicated that the raw water source contained enteric viruses (Deetz et al., 1984). Raw water is withdrawn from a river and conveyed approximately 17 km by canal to the treatment plant via two pumping stations.

The river is fed by a shallow lake located in a watershed with a human population of 4 to 8 million. Wastewaters discharged into the watershed are not treated. The treatment facility consists of five separate plants constructed over a 20-year period (1955-1975). Each plant has a treatment sequence consisting of chemical addition (liquid alum and catfloc or superfloc) followed by hydraulic mixing, flocculation, clarification with pre- and post-chlorination, filtration through rapid sand filters or automatic valveless sand filters and final chlorination. All samples were collected from three of the five plants. Samples collected included raw water (intake water), water post-clarification, water post-filtration and finished water (Figure 1). Four trips to the plant were made and 20 to 40 samples collected during each trip.

ENGINEER EVALUATION

On November 16-19, 1981, and April 7 and 8, 1983, engineering evaluations of the Guadalajara Water Treatment Plant were conducted. The purpose of the evaluations was to provide supporting information on, the nature of the operation of the plant during the study period and to identify any important operational and design deficiencies that might relate to the microbiological findings.

VIRUS SAMPLE COLLECTION

Samples of 9.8 to 756 liters were collected using 1 MDS Virosorb filters [AMF CUNO, Meriden, CT] (Sobsey and Glass, 1980). An electric, one horsepower centrifugal pump was used to collect samples that could not be collected directly from taps. Where necessary, in-line injectors [DEMA, St. Louis, MO] were used to inject sodium thiosulfate into water to neutralize the chlorine before passage through the virus-adsorbing filters (Payment and Trudel, 1981). Samples were collected from the canal at the plant intake and in the plant at points after clarification, after filtration and after final chlorination. On each day that samples were collected, finished water samples were collected first and intake water samples last in order to minimize the possibility of contamination of the finished water samples. Separate filter housings and hoses were used for each sampling location. The filter housings were disinfected by soaking for 30 minutes in buckets filled with water containing more than 5 mg/L of free chlorine. Hoses and pumps were disinfected by pumping water containing greater than 5 mg/L of free chlorine through them for 30

minutes. Concurrently, 1-L grab samples were collected for analysis of bacteria, bacteriophage and turbidity.

On the last day of each sampling trip, poliovirus type 1 (LSc-2ab) was seeded into 200 L of dechlorinated finished tapwater; the water was then processed in the same manner as the other samples. This last sample, kept separate from other samples during shipment and handling, served as a positive control.

A negative control was prepared from Tucson tapwater that had been exposed to 5 mg/L of residual chlorine for 30 minutes. Other negative controls were prepared from 1-L volumes of autoclaved 3% beef extract.

VIRUS CONCENTRATION PROCEDURES

Adsorbed viruses were eluted by passage of 1-L of 3% beef extract pH 9.5 [Scott Laboratories, Fiskeville, RI], into the filter housing in the same direction as the water flow. The pH of the eluting solution was adjusted just before use by adding 1 N NaOH. Once the housing was filled, the beef extract solution was allowed to remain in the housing for 2 to 5 minutes, then forced out of the housing with air. The pH of the eluate was immediately adjusted to 7.0 to 7.5 by adding 1 N HCl. Samples were packed in crushed ice for shipment to the laboratory at the University of Arizona for one to six days prior to being frozen (-20°C) for preservation before final processing.

ENTEROVIRUS AND ROTAVIRUS DETECTION

Primary filter eluates were thawed and reconcentrated from a volume of 1 L to approximately 36 ml by an organic flocculation method described by Katzenelson et al. (1976). The final concentrate was divided into three volumes: 10 ml were examined for enteroviruses, 10 ml were examined for rotaviruses and the remaining volume was stored at -20°C for future use.

All samples were processed under code so that their identity was not known to laboratory personnel conducting the analysis. Samples for enterovirus analysis were inoculated onto monolayers of BGM cells, 2 ml/75 cm^2 plastic flask, overlaid with maintenance medium and observed for cytopathic effects (CPE) for a period of 21 days. Samples that did not produce CPE were passed an additional two times on monolayers of BGM cells and observed for 14 days for CPE on each passage.

Those samples positive for CPE were passed a second time in the BGM cell line and then plaqued as a final confirmation of the presence of virus using an agar overlay method (Melnick et al., 1979). Subsequently, virus isolates were identified by serum neutralization tests using the Lim-Melnick enterovirus antibody serum pools (Melnick et al., 1973).

Rotaviruses were detected by inoculating cultures of MA-104 cells (Smith and Gerba, 1982) in Lab-Tek glass chamber slides (Miles Laboratories, Naperville, IL) in the presence of medium containing trypsin (0.5 ug/ml Sigma Type IX, Sigma, St. Louis, MO). To reduce interference by the growth of other enteroviruses a 24 hour incubation was used at 37°C, after which the medium was aspirated off, the chamber removed and the monolayers fixed in methanol at -20°C for 5 minutes. The slides were then stained by the fluorescence assay described by Smith and Gerba (1982).

Primary guinea pig or rabbit antisera directed against human rotavirus were obtained from the NIAID Reference Reagents Laboratory (Bethesda, MD), and from DAKO (Accurate Chemical and Scientific, Westbury, NY). Secondary antisera conjugated with FITC was obtained from Miles Laboratories (Elkhart, IN).

GRAB SAMPLES

One-L grab samples and virus samples were taken simultaneously. The procedure for the grab sample collections as recommended in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1980) included the use of sterile bottles containing sodium thiosulfate (0.5%, w/v) to neutralize residual chlorine.

Coliphage and bacterial densities, as well as the physical-chemical properties of the water were determined from each grab sample. A portion of each sample was transported on ice to the University of Arizona for analyses that were not performed on site (i.e. coliphage). Depending on the day each sample was collected, transport time ranged from one to six days prior to analysis.

COLIPHAGE ASSAYS

Bacteriophage concentrations were determined in the grab samples as well as in each 1 MDS filter eluate, before freezing, using Escherichia coli Hfr (ATCC 15597) as the host bacterium. Ten ml of each sample were assayed by the plaque technique using a soft-agar overlay method (Adams, 1959). Penicillin G (300 mg/L) was added before assay to samples

containing high concentrations of bacteria.

BACTERIAL ASSAYS

Bacterial analyses were performed immediately from the grab samples for standard plate count bacteria, total and fecal coliform bacteria, and fecal streptococci bacteria. The membrane filtration method was used to enumerate the bacteria, with appropriate temperatures and incubation times (APHA, 1980). Nalge Nutrient Pad Kits (Rochester, NY) were used for consistancy and ease of handling. The use of Nalge Kits is not approved by Standard Methods and a comparative evaluation was not undertaken in this project. All media expiration dates were adhered to and freshly prepared endo medium was used during the April, 1983 sampling trip for total coliforms. Appropriate dilutions were made and 10 ml, 50 ml, 100 ml and for some samples 200 ml volumes were filtered. Enterococci were also enumerated in 30 samples using a MF method developed by Levin et al. (1975). Media and filters were tested with Escherchia coli or Streptococcus faecalis prior to use in the study.

Positive colonies isolated on the membrane filters for total and fecal coliforms from finished drinking water were transferred to nutrient agar slants. The coliform isolates were submitted to presumptive and confirmative tests. A percentage of presumed non-coliform colonies isolated from the membrane filters were also tested in the same manner in order to detect false negatives.

Positive fecal coliform isolates were confirmed by passage into EC broth, incubation at 44.5°C for 48 hours with gas production constituting a positive test.

Selected colonies of fecal streptococci were confirmed by their growth on KF fecal streptococcus medium and subsequent development of the typical pink to red colonies.

PHYSICAL-CHEMICAL MEASUREMENTS OF WATER QUALITY

Total and free chlorine levels were determined by the DPD colorimetric method using a Hach Chemical Chlorine Kit (model CN-70). The pH was determined using a Hach Digital pH Meter (Model 18800, Hach Chemical, Loveland, Co.); this was standardized several times daily with pH 4, 7 and 10 buffers. The pH probe was disinfected between samples by placing it in a solution of 1 N HCl for 10 minutes. Samples for turbidity testing were packed in ice and transported (post one to six days) to the University of Arizona where turbidities were determined using a Hach Turbidimeter (Model 2100A, reported as nephelometric turbidity units, NTU).

QUALITY ASSURANCE

Water quality data obtained during the course of the study was compared to results obtained by the treatment plant personnel. Plant records were obtained for each sampling trip to compare the data obtained by the most probable number method for coliforms and to compare other water quality criteria (i.e., turbidity). Gross differences in results could then be noted.

Stool specimens or fecal swabs were collected from each of the laboratory personnel coming in contact with the virus samples during collection, and assayed for enteroviruses. All personnel wore disposable

gloves when handling filters or samples throughout the course of analysis. The specimens were processed and inoculated onto cell cultures in designated areas physically separated from areas where laboratory strains of viruses were in use. All samples including positive and negative controls were coded with numbers and laboratory personnel were not aware of the source of the sample until completion of all assays and confirmatory tests.

STATISTICAL ANALYSIS

Prior to analysis, the biological data (plate counts, plaque counts, fluorescence foci counts) were transformed appropriately ($\log_{10}(y + 1.0)$). Presence or absence of enteroviruses and rotaviruses was entered as a dichotomous variable (1.0 or 0.0). Samples with indeterminate data (i.e. ">" values) or non-determined data (N.D.) were excluded from the analysis. Out of 50 raw, clarified and filtered water samples, 14 were excluded from the analysis, with six and eight samples positive for enteroviruses and rotaviruses, respectively. Out of 63 finished water samples, 22 were excluded from the analysis with two of the samples positive for enteroviruses. All of the rainy season data was excluded as many bacterial counts were indeterminable or not obtained, including eight samples, all which were positive for rotavirus. Fifteen variables including volume, pH, total chlorine, free chlorine, turbidity, total plate count bacteria, total coliforms, fecal coliforms, fecal streptococci, coliphage (by the direct method), coliphage (in the concentrate), enteroviruses (presence$^+$/absence$^-$), rotavirus counts, rotaviruses (+/-), and total enteric viruses (+/-, either enterovirus or rotavirus) were analyzed for linear intercorrelation by calculating Pearson's product-moment correlation coefficient (r) and multiple regression correlation coefficients (R) using the Cyber 175 and DEC-10 computers at the University of Arizona Computer Center with the Regran Program (Veldman, 1967).

For associations among the 15 variables, Pearson's correlation coefficients were computed using the data obtained from the 36 samples of raw, clarified and filtered water, and computed separately using data from the 41 samples of finished water.

SECTION 5

RESULTS

Four sampling trips were made over a 2-year period to the water treatment plant under study. In 1982, samples were collected during the dry season in March and during the rainy season in July. In 1983, collections were taken during the dry season in January and April. Physical-chemical, bacterial, and viral analyses were performed on each sample; these results are shown for raw water (Table 1), clarified water (Table 2), filtered water (Table 3) and finished water (Table 4).

A total of 113 samples was collected during the course of the study. Twenty-one samples were collected from raw water at the intake, 16 samples from water after pre-chlorination/clarification, 13 samples from water after filtration and 63 samples from finished water after post-chlorination. The volume of water filtered for enteric virus analysis averaged 89 L, 82 L, 280 L, and 439 L for the raw, clarified, filtered and finished water, respectively. The high turbidities in the raw water in some cases influenced the volume that could be passed through the filter. Other variables such as organic content, alum addition, and floc formation may have caused premature clogging during collection of samples within the plant.

Water was pre-chlorinated as it entered the plant giving an average of 0.6 mg/L and 0.8 mg/L of free chlorine in the water post-clarification and post-filtration, respectively. After final chlorination, the finished

water contained an average of 1.6 mg/L of free chlorine with only two samples having less than 0.5 mg/L.

Table 5 summarizes the data on enteric virus isolation from all samples collected during the dry season. Viruses were recovered from 68% of the raw water samples. After pre-chlorination/clarification and filtration, seven (50%) and three (37%) of the samples were respectively positive for viruses, and viruses were detected in 11 (20%) of the finished water samples. Eight (24%) of the finished water samples which contained >0.2 mg/L free chlorine residual and met turbidity and bacterial standards were positive for enteric viruses. In the clarified, filtered, and finished water, rotaviruses were detected more frequently than enteroviruses. Both rotaviruses and enteroviruses were found in five raw water samples, two samples post-clarification, and in one finished water sample, but not in post-filtration water samples.

The mean values for turbidities, bacteria and viruses were calculated for each sampling trip during the dry season (July, 1982; January and April, 1983) as well as the combined means (weighted by number of samples per trip) for the data from the raw, clarified, filtered and finished water samples (Table 6). In general the total plate count bacteria were found to be the most numerous, ranging from 9/ml in the finished water to 465/ml in the raw water, followed by the fecal streptococci (20 to 4452/100 ml), enterococci (6 to 1165/100 ml), total coliforms (1.5 to 216/100 ml) and fecal coliforms (1 to 66/100 ml). Plant records showed comparable results. False negative colonies for total and fecal coliforms were not detected in the finished water. False negative coliform colonies were encountered in samples of raw water which had high counts of non-coliform bacteria. Enterococci were enumerated only during the January 1983 collection trip.

Coliphage concentrations, as determined from 1-L grab samples, ranged from 1 to 1769/L from the finished and raw water respectively. However, the numbers found in the filter eluates never equalled the numbers found in the direct sample. In some instances coliphage were detected in the direct grab sample but were not found in the concentrate.

The water quality decreased during the rainy season (July, 1982 trip) as indicated by relatively high turbidities, bacterial numbers and coliphage counts in the raw water as well as in the finished water (Table 7). Enterovirus isolation was not enhanced during the rainy season; however, the rotavirus counts were elevated in July for all samples except in the raw water.

Table 7 contrasts turbidities, coliform bacteria, free chlorine and virus isolation between the dry and rainy seasons for finished water. Turbidity averaged 1.04 NTU for the samples collected during the dry season and increased to 9.63 NTU during the rainy season due to storm runoff. Coliform bacteria averaged 1.76/100 ml for the dry season and averaged 1750/100 during the rainy season, far exceeding recommended standards. Free chlorine measured 1.57 mg/L during the dry season and decreased to 0.74 mg/L during the rainy season. The increased incidence of coliphage and rotavirus during the rainy season also reflected the poor water quality during this period.

Average percent reductions for all water quality variables studied were determined after each step in the water treatment processes during the dry season (Table 8). Reductions were calculated for each collection trip and overall for the dry season from the means (see Table 6). The samples post-chlorination/clarification were collected during the 3/82 and 1/83 trips and samples post-filtration were collected during the 1/83 trip.

Only these samples were used to determine the reductions after these treatments. Major reductions in bacteria and coliphage (90% to 99%) came after pre-chlorination/clarification with slight decreases during the other treatment steps.

The greatest decrease in enteroviruses occurred during pre-chlorination/clarification and filtration steps. The reduction of rotaviruses occurred after pre-chlorination/clarification and chlorination of the finished water. The enteric viruses had the lowest percent reduction during the treatment process of all the microorganisms studied. The greatest reduction in turbidity occurred after filtration and averaged 87% after complete treatment.

By comparing the removal efficiencies for the rainy season to those for the dry season alone, it was found that the removal efficiencies increased from 63% to 87% for turbidity, from 95.4% to 99.3% for total coliforms, from 87.8% to 99.9% for coliphage (by the direct method), from 78% to 81% for enteroviruses, and from 0% to 93% for rotavirus.

The normal chlorine contact time of 30 minutes was extended 30 and 60 minutes for 6 samples by placing 600 L of chlorinated finished water into large sterile barrels. The results are shown in Table 9. No coliforms, fecal coliforms or fecal streptococci were isolated from 5 of the 6 samples. In one sample held for 60 minutes, total and fecal coliforms as well as fecal streptococci were present. No enteric viruses were isolated from any of the six samples. Higher levels of total plate count bacteria, total coliforms, fecal coliforms, fecal streptococci and rotaviruses were observed in samples prior to this extension. However, only one sample out of six contained rotaviruses.

Table 10 shows the results obtained in the raw and finished water

sampled hourly over a period of 7 hours taken during the last collection trip. Turbidity, total plate count bacteria, fecal streptococci bacteria, and rotavirus counts in the raw water were elevated during the afternoon. The same trend was found in the finished water samples.

Enteroviruses were isolated from a total of 23 samples collected during this study: ten were from raw water samples, five from samples post-chlorination/clarification, two samples from post-filtration, and six from finished water samples. These were identified on BGM cells using the Lim-Melnick antibody serum pools (Table 11). Of the 53 isolates, ten were coxsackievirus B5, seven were echovirus 9, five were poliovirus 1, four were coxsackievirus B6 and two were echovirus 24. Six isolates produced plaques but were not neutralized using the antibody pools. Identification was not attempted on the remaining 19 isolates as discussed below.

All isolates produced CPE initially on a BGM monolayer and were then confirmed by production of CPE by a second passage on BGM cells. The isolates were then plaqued for additional virus confirmation using an agar overlay method. Eight of the isolates did not produce plaques but did yield CPE by a third passage on BGM cells. The 19 isolates which failed to produce plaques were examined using transmission electron microscopy (TEM). Volumes of approximately 0.1 ml from each sample (second passage) were fixed in paraformaldehyde and were negatively stained using phosphotungstic acid and viewed under TEM for virus particles. Two isolates were negative under TEM perhaps because of an insufficient titer. Seventeen isolates were positive for virus-like particles when examined by TEM and ranged in size from 22 to 30 nm. Further identification was not attempted.

Pearson's product-moment correlation coefficients were calculated using 36 samples of raw, clarified and filtered water (Table 12) and 41

finished water samples (Table 13). The presence or absence of enteroviruses and rotaviruses were analyzed as dichotomous variables. The fluorescent foci counts for rotaviruses were included separately after $\log_{10}(y + 1.0)$ transformations. Total enteric viruses were analyzed by the presence or absence of either enteroviruses or rotaviruses or both as a dichotomous variable.

In the raw, clarified and filtered water samples (raw samples; Table 13), significant negative correlations existed between free chlorine and the bacterial counts and phage counts (-0.41 to -0.55). A significant positive correlation was found between the bacterial counts and turbidity and phage counts and turbidity (0.38 to 0.73). The bacterial and phage counts were also significantly correlated (0.48 to 0.70).

The occurrence of enteroviruses was significantly correlated to the total plate count bacteria and phage counts (in the concentrate) for the raw water samples 0.36 and 0.33, respectively (Table 13). No significant correlations were found between the rotaviruses and other variables in these samples.

In the finished water samples (Table 13), no significant correlations were found between fecal coliforms and the other variables while total coliforms were significantly correlated to turbidity (0.72), and total plate count bacteria (0.36). Fecal Streptococci were also significantly correlated with total plate count bacteria. It was interesting that while the coliphage in the direct sample remained significantly correlated to turbidity, total plate count bacteria and total coliforms (0.79,0.41 and 0.85, respectively), the coliphage in the concentrate was not associated with these variables.

In the finished water samples (Table 13) no significant correlations

were found between the presence of enteroviruses, total plate count bacteria and phage counts as too few samples contained virus. Rotavirus counts as well as the occurrence of rotavirus were found to have a significant negative correlation to free chlorine (-0.39; -0.46) and a significant positive correlation to coliphage counts (direct sample)(0.38; 0.53). Rotavirus counts had a positive significant correlation to total coliforms (0.37), and turbidity (0.40), while the presence of rotaviruses was not significantly correlated to these variables.

The intercorrelations were examined further by multivariate linear regression analysis. Four model equations using either enteroviruses or rotaviruses as the criterion variable were evaluated. The first or "full" model incorporated variables 1 to 11 (identified in footnote, Table 15). The second model incorporated only the physical and chemical data (variables 1 to 5). In the third model equation, only the bacterial data (variables 6 to 9) were considered and model four was the same but for the addition of the variable representing coliphage counts. These four model equations were used to investigate the multiple correlation of the selected variates with presence or absence of either enteroviruses or rotaviruses in both raw and finished water. In addition, these equations using either rotavirus counts or presence of either of the enteric viruses as criteria were developed employing only the finished water samples. The extent of the association of the variables to the chosen criteria variables is measured by R^2, the square of the multiple correlation coefficient R. The R^2 value is interpreted as the percent of variation in the criterion variable that is "explained" by the variation in the other incorporated variables and the statistical significance can be evaluated by a multivariate F ratio. These R^2 values are presented in Table 15 for the

model equations evaluated. Approximately 33% and 39% of the variation in the detection of enteroviruses was associated with the variation in the 11 variables in the raw and finished water samples, respectively. By multivariate F ratios, it was determined that these R^2 values were not statistically significant. Similar results were obtained for the presence of rotaviruses and total enteric viruses. In the finished water samples, approximately 48% of the variation in rotavirus counts was associated with the variation of all 11 variables, whereas 39% was associated with the variation in the bacterial and coliphage counts (variables 6-10). These R^2 values, although seemingly unimpressive, were statistically significant. The addition of coliphage counts to the bacterial counts (model equation 4 vs. equation 3) did not significantly increase the R^2 value.

ENGINEERING EVALUATION

During the evaluations of the drinking water treatment facility on November 16-19, 1981, and April 7 and 8, 1983, the following observations were noted.

The coagulant dosage was 31 mg/L alum and 0.6 mg/L catfloc which resulted in a floc with good settling properties as determined by the jar test. However, *in situ* mixing of the chemicals with the entire volume of water was often poor as proper turbulence for rapid mix was not provided by hydraulic pumps. As water volume increased, mixing was probably less effective. Many clarifiers were overloaded with weirs submerged which resulted in the floc passing over to the filters and short circuiting. Algal growth was observed in all the clarifiers.

Filters were subjected to variable rates and surges. Short filter runs were occurring (15 minutes to one hour) in some cases, and some filters were being operated every 24 hours prior to backwash regardless of breakthrough. The filter media also showed clear evidence of cracking and mudballs. Ineffective backwash was indicated by mudballs and media grains. Filters not in service were heavily coated with floc. During backwash, sand boils appeared indicating displacement of support bed and shortcircuiting. Sand boils are indicative of a serious filter problem. Valves for the conventional filters were operated manually and some of the conventional as well as the valveless filters were out of service due to plugged underdrains.

Operators reported a chlorine contact time of less than 30 minutes during peak periods, dropping to as low as 15 minutes.

Plant records indicated turbidities ranging from 1.0 to 6.0 NTU and

chlorine residuals from 0.5 mg/L to 1.5 mg/L in the final water for April, 1983.

Overall numerous deficiences were identified. The plant may have been operating near or above its design capacity (hydraulically overloaded), but the extent of the problem could not be determined due to the lack of metering.

SECTION 6

DISCUSSION

A drinking water treatment plant that processed the incoming water by pre-chlorination/flocculation, sand filtration, and final chlorination was chosen for the study. This plant produced water of varying quality, providing an opportunity to study the effectiveness of virus reduction under a wide range of conditions.

Four sampling periods were chosen, three during the dry season when the plant was operating optimally and one during the rainy season when the plant could not produce water meeting minimum coliform and turbidity standards (EPA, 1975).

Rotavirus concentrations were greatest in the raw water during the rainy season and easily penetrated the overloaded treatment process. The rainy season is associated with a dramatic decrease of raw water quality because of large amounts of sediment produced by storm run off. It was evident that even application of large amounts of chlorine (> 10 mg/L) could not prevent the occurrence of coliform bacteria and rotavirus in the finished water when the concentration of suspended matter was large. Surprisingly, only one sample yielded an enterovirus. Perhaps this is because of lower recovery efficiency of the enteroviruses caused by the high turbidity interference.

The arithmetic mean for turbidity in the finished water during the dry season was within current standards (EPA, 1975) of 1 NTU. Because of the presence of a few samples containing elevated coliform counts taken during the last sampling period, the arithmetic average was 1.76/100 ml for all

dry season samples. The higher coliform numbers seen in samples from the final sampling trip may have been due in part to the larger volumes tested (i.e., 200 ml). The best finished water quality occurred during the third sampling trip when the arithmetic mean for turbidity averaged 0.79 NTU, total coliforms averaged 0.35/100 ml, and free chlorine averaged 1.6 mg/l. Bacteriologically, the best water quality occurred during the first sampling period when no coliforms were detected in the finished water, although fewer samples of finished water were taken during this sampling period.

Enteric viruses were isolated from finished water during all three dry-weather sampling periods. Overall, enteric viruses were isolated from 20% of the finished water samples. Enteric viruses were isolated from 24% of the samples that met standards for coliform bacteria and turbidity, and the free chlorine level greater than 0.2 mg/L. An interesting note was that only a small percentage of samples contained both enteroviruses and rotaviruses. Although an equal number of raw water samples were found to contain either enteroviruses or rotaviruses, rotaviruses were more commonly isolated in the clarified, filtered and finished waters (Table 5). Although enteric viruses were isolated from only a limited number of samples, the results suggest that rotaviruses may not be removed as efficiently by sand filtration as are enteroviruses and the major effect at the clarification step may have been due to the pre-chlorination. Previous studies by Farrah et al., (1978) and Steinmann and Havemeister (1982) found that Simian rotavirus SA-11 was removed noticeably less well than poliovirus type 1 by aluminum hydroxide flocs. Farrah et al. (1978) also reported that human rotavirus particles present in dilute stool suspensions were not noticeably reduced from water by alum flocs. Thus,

both laboratory and field studies would suggest that rotaviruses are less efficiently removed by flocculation and filtration than are enteroviruses.

Although rotaviruses occurred much more frequently in all finished water samples, both rotavirus and enteroviruses were isolated from an equal number (4 and 5 respectively) of finished water samples meeting coliform and turbidity standards and having a free chlorine content of 0.5 mg/L or greater.

Overall, reduction of enteroviruses was 81% and rotavirus reduction was 93% (9/47 and 1/15, respectively, samples positive for virus in finished water/samples positive for virus in raw water) during the optimal operation of the plant. Of all the groups of microorganisms studied, enteric viruses were the least effectively reduced. Greater than 99.9% reduction of the coliphages occurred.

The low recovery of coliphages in the filter eluates as compared to the direct assay indicated that they were poorly concentrated or inactivated by the methods used for enteric virus concentration. Many factors may have contributed to the lack of phage detection in these samples such as inactivated during concentration, elution with the high pH beef extract (Goyal et al., 1980), or storage during transport back to the laboratory. Perhaps a modified procedure designed specifically for phage may be more conducive to their detection in large volumes since the coliphage appear to be more sensitive than enteric viruses to external conditions such as high pH.

The tests for determining the chemical, physical and bacteriological quality of the water are relatively simple and expedient, thus it was of some interest to evaluate any associations these groups of variables may have to the virological quality of the water. Coliphage were also included

because it has been suggested that these bacterial viruses may be more indicative of the presence of animal viruses. Although some statistically significant correlations were found based on bivariate (r) coefficients and multiple regression (R) coefficients, these correlations must be regarded as very tentative and inconclusive based on the small size of the samples.

Analysis indicated that low, but statistically significant relationships existed between the total plate count bacteria, coliphage counts and the presence of enteroviruses in the raw water. It was found that while a significant correlation existed between the presence of rotaviruses and coliphage counts in the finished water, this was not the case in the raw water samples. There may be greater interference with the isolation and detection of these viruses in these heavily polluted samples. Failure to find other significant relationships may in large part be attributed to the limited number of samples in which virus was isolated and to the limitations of the various methods used. For example, better methods for coliphage concentration and detection may have strengthened the observed relationships. From this study it was also clear that coliform, fecal coliform and fecal streptococci bacteria were not good indicators of the presence of enteric viruses. Too few samples were analyzed for the presence of enterococci to determine if a relationship exists between their occurrence and that of enteric viruses.

In six samples of finished water (collected 4/83) the contact time of the sample was extended after chlorination for 30 and 60 minutes before virus sampling (Table 9). The free chlorine ranged from 1.4 to 1.6 mg/L after 30 minutes and was 1.2 mg/L after 60 minutes. No viruses were detected in any of these samples although in one of the samples, coliforms and fecal coliforms were detected. The detection of the indicator bacteria

may be due to the larger volume tested (i.e. 200 ml), high pH of sample (8.3) making chlorine less effective, or experimental error. Unfortunately, only one sample in six yielded rotavirus in the finished drinking water prior to the extended chlorine exposure, and no enteroviruses were isolated. Thus it is uncertain whether the maintenance of a free residual chlorine of at least 1.4 to 1.6 mg/L would result in production of virus-safe water if contact time is sufficient.

The highest concentration of rotavirus in the raw source water occurred during the rainy season when it reached 232 immunofluorescent focI(i.f.)/L. Concentrations in the range of 1 to 15 i.f./L were more common. Concentrations in those samples of finished water from which it was isolated varied from 7 to 10,448 i.f. /100 L. Concentration and detection methods are far from 100% efficient and the concentration of viruses is undoubtedly greater than that observed in this study. Also, samples were not considered positive for rotaviruses unless more than one focus was observed in a sample by two different observers on samples assayed separately. Thus, detection of very low levels of rotaviruses would be excluded by this control procedure.

As indicated by the engineering evaluations of the plant on November 16-19, 1981, and April 7 and 8, 1983, the plant was not operating optimally and several major engineering deficiences in the treatment process were noted. During the rainy season the plant was incapable of producing water meeting acceptable microbial and turbidity criteria. Still the plant was capable of producing water during most of the dry season which would meet coliform and turbidity standards.

It is difficult to compare studies on the relative efficiencies of treatment processes on microbial reduction because of differences in

treatment sequences (Table 15). For example, in the present study greater reduction of bacterial indicators were observed after clarification than by Stetler et al. (1981), but this was probably due to the practice of pre-chlorination of the incoming water at Guadalajara. The percent reduction of microorganisms was similar at both plants after filtration, but greater reduction of coliforms, fecal coliforms and fecal streptococci occurred after chlorination (Table 16). This is probably due to the higher level of free chlorine (2.3 mg/L) at the plant studied by Stetler et al. (1984) as compared to Guadalajara (1.57 mg/l). It was interesting that a greater reduction of total plate count bacteria occurred at Guadalajara than at the plant studied by Stetler et al. (1984).

Enterovirus reduction at Guadalajara after clarification were comparable to that observed by Stetler et al. (1984), although filtration was about equally ineffective at both plants. Again, the higher levels of free chlorine and perhaps greater contact time at the plant studied by Stetler et al. (1984) may have accounted for the greater reduction of enteroviruses overall.

Payment and Trudel (1984) have also recently studied the reduction of enteroviruses at seven drinking water plants in Canada. The treatment process at the plants varied but most practiced pre-chlorination, coagulation, filtration and final chlorination. Three of the plants practiced ozonation before final chlorination. Samples were obtained at each level of treatment. All plants were capable of producing water that was free of coliforms, fecal coliforms and fecal streptococci when one liter samples were tested for these organisms. Average turbidities for five plants practicing complete treatment was always less than 1.0 NTU, and average free chlorine was always equal to or greater than 0.4 mg/l. During

this study it was observed that while total coliform reductions were as great as >99.9999%, viral reduction did not exceed 99.998% at maximum efficiency. The average virus reduction for all plants was 99.98%. The authors also observed that no significant inactivation of enteroviruses occurred after ozonation or final chlorination. Enterovirus removal after pre-chlorination/clarification averaged 78%, as compared to 55% observed in this study. Filtration resulted in a further reduction of 48% in enteroviruses, as compared to the 62% observed at Guadalajara.

In the study conducted by Payment and Trudel (1984) enteroviruses were detected in 7.1% (11/155) of the finished drinking water samples (1000 liter) and in none of the 36 1,900-liter samples by Stetler (1984).

Drinking water in the United Kindom has been monitored for several years, and Tyler (1982) has reported the isolation of enteroviruses in 24 samples of finished drinking water which contained no detectable coliforms (per 100 ml) or E. coli. Sixty-seven percent of the samples contained free chlorine levels equal to or greater than 0.2 mg/L.

No previous studies on the occurrence of rotaviruses in drinking water have been conducted. Since the initiation of this study we have isolated rotaviruses in treated drinking water at another plant meeting current bacterial, turbidity and recommended levels of chlorine (Gerba et al., 1984). From the results of this study it appears that rotaviruses are not as effectively removed by filtration as enteroviruses although chlorine is highly effective in their inactivation. Since rotaviruses have caused documented outbreaks of waterborne disease (Sutmoller et al., 1982; Zmotin et al., 1981; Lycke et al., 1978; Tulchinsky et al., 1983; Hopkins et al., 1984) additional studies are needed to assess their occurrence in raw and treated drinking waters.

The high fecal streptococcus levels in the raw water indicate that much of the microbial contamination may have been of animal origin. Many animals are also known to excrete rotaviruses (Gerba et al., 1984), and it is possible that the rotaviruses which were detected were of animal origin. In a previous study at the same water treatment plant we performed neutralization tests on the rotavirus isolates which indicated that most of the rotaviruses were of human origin (Deetz et al., 1984).

Finally, it should be realized that only two-thirds of the volume of the final concentrate of each sample was assayed. Thus the actual number of samples containing virus could be greater than that reported. The final one-third of the samples is being saved until better methods are available for the detection of hepatitis type A virus (enterovirus type 72).

From this study and others, (Melnick and Gerba, 1982; Payment, 1981; Payment and Trudel, 1981), it appears that enteric viruses can occur at detectable levels in finished drinking water meeting current coliform and turbidity standards and containing a significant level of free chlorine (0.2 mg/L). The isolation of human enteric viruses in these waters is not a condemnation of conventional drinking water treatment, but an indication that water quality criteria currently accepted to ensure the production of microbially safe water do not necessarily ensure the absence of enteric viruses. The engineering evaluation of the Guadalajara water treatment plant indicated numerous major deficiencies in the treatment plant which could explain the occurrence of enteric viruses in the finished water. However, these deficiencies did not seem to be consistently reflected in the quality of the finished water during the dry season in regard to total coliforms and turbidity. It may be that in marginally operated water treatment plants or plants with a heavily contaminated raw water source,

measurable levels of enteric viruses are able to survive the treatment process even when current water quality standards are achieved.

From the results of this study and other similar field studies it is difficult to define those operational conditions at a treatment plant under which all measurable levels of virus would be removed. It is also uncertain if other microbial indicators such as coliphage would better reflect treatment removal of enteric viruses. Because enteric viruses were isolated infrequently in the treated drinking water, it was difficult to establish statistically significant relationships. Further research should be conducted to define treatment operational conditions which allow viruses to occur in drinking water while other water quality characteristics are satisfactory. Also, better indicators of treatment plant efficiency for enteric virus removal should be sought.

One approach to the development of better criteria might be the use of small pilot plant studies in which mixtures of sewage are used as a raw water source. This would allow determination of the removal of mixtures of naturally occurring enteric viruses as well as other microbial indicators by the treatment process. In addition, operational conditions could be rigidly controlled, varied and monitored. Use of a pilot plant facility would also greatly reduce virus collection costs (i.e. travel costs) and a more meaningful number of virus samples could be collected, thus improving comparisons between operational water quality indicators and the removal of enteric viruses.

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Figure 1. Diagram of water treatment plants and collection sites.

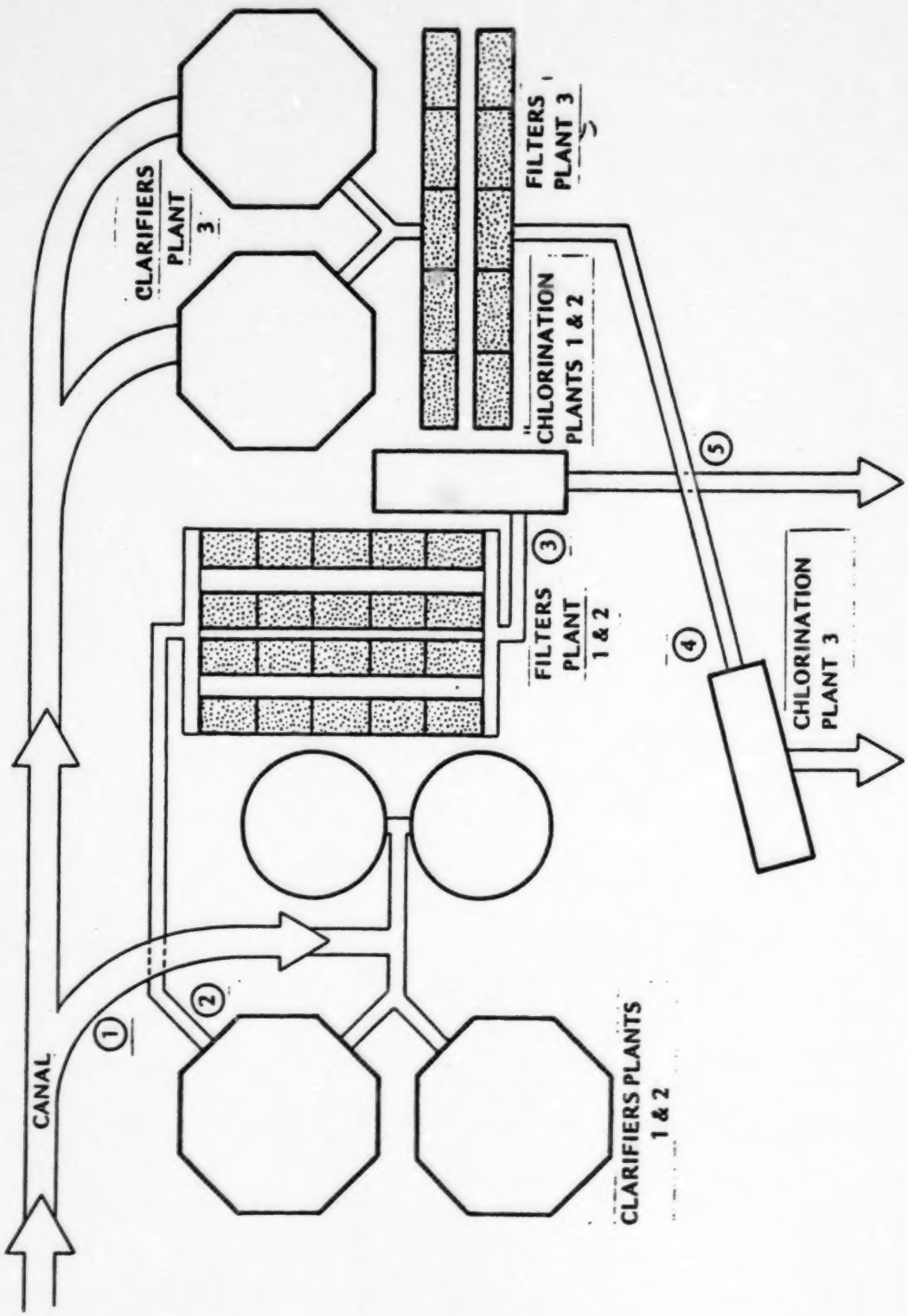

TABLE 1. PHYSICAL-CHEMICAL, BACTERIAL AND VIRAL QUALITY OF RAW WATER SAMPLES FROM A DRINKING WATER TREATMENT FACILITY

Sample No.	Date	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Bacteria/100 ml: Total Plate Count/ml	Total Coliforms	Fecal Col'forms	Fecal Strep	Entero-cocci	Viruses: Coliphage/[a] 1 L (Direct)	Coliphage/ 1 L (Concentrate)	Enterovirus CPE #+/# Tested	Rota-virus/ 100 L
5	3/02/82	76	7.6	0	0	ND	340	240	140	3,400	ND[b]	1400	158	1/3	248
6	3/02/82	67	7.6	0	0	ND	340	240	140	3,400	ND	ND	ND	3/5	1,202
11	3/03/82	65	8.0	0	0	6.1	170	1,500	140	1,820	ND	0	323	3/3	1,163
12	3/03/82	111	8.0	0	0	6.1	170	1,500	140	1,820	ND	ND	156	0/4	324
19	3/04/82	77	ND	0	0	7.1	ND	ND	940	ND	ND	2100	3,801	3/3	94
26	7/19/82	15	7.6	0	0	23.0	6,200	73,000	9,000	132,000	ND	7600	11,533	1/9	3,491
31	7/20/82	10	7.2	0	0	29.0	1,020	20,000	0	89,000	ND	1800	11,000	0/5	0
57	1/25/83	7	8.0	ND	ND	3.3	580	2,400	0	18,100	1,400	1300	1,071	2/8	0
58	1/25/83	19	7.7	ND	ND	3.6	780	1	0	6,900	1,300	2000	1,042	1/5	0
69	1/26/83	98	7.9	ND	ND	4.1	690	15	50	7,000	870	6000	1,500	5/5	0
70	1/26/83	126	7.9	ND	ND	ND	ND	ND	ND	ND	ND	6000	1,167	0/5	0
82	1/28/83	130	8.0	0	0	2.6	390	100	0	9,500	ND	4400	969	0/5	0
86	1/28/83	113	7.9	ND	ND	ND	4,000	460	150	97,000	ND	ND	1,040	0/5	0
99	4/07/83	148	8.1	0	0	8.3	520	900	100	4,000	ND	1200	426	2/5	0
100	4/08/83	100	8.2	0	0	8.9	263	420	390	300	ND	2200	2,800	0/5	0
101	4/08/83	82	8.1	0	0	6.3	273	480	280	800	ND	1800	1,085	0/5	0
102	4/08/83	67	8.2	0	0	11.0	480	460	180	1,300	ND	2000	821	0/5	203
103	4/08/83	82	8.1	0	0	25.0	420	420	140	3,500	ND	1800	1,256	0/5	0
104	4/08/83	84	8.2	0	0	11.0	660	210	60	9,100	ND	1800	464	1/4	166
105	4/08/83	81	8.2	0	0	10.0	560	80	80	12,000	ND	2000	259	0/5	592
106	4/08/83	311	8.3	0	0	6.3	510	40	170	7,200	ND	1200	193	0/5	97

[a] Water sample plated directly on E. Coli Hfr host bacteria

[b] ND = Not determined

TABLE 2. PHYSICAL-CHEMICAL, BACTERIAL AND VIRAL QUALITY OF CLARIFIED WATER SAMPLES FROM A DRINKING WATER TREATMENT FACILITY

Sample No.	Date	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Bacteria/100 ml: Total Plate Count/ml	Total Coliforms	Fecal Coliforms	Fecal Strep	Entero-cocci	Viruses: Coliphage/[a] 1 L (Direct)	Coliphage/ 1 L (Concentrate)	Enterovirus CPE #+/# Tested	Rota-virus/ 100 L
3	3/02/82	128	7.8	1.4	0.3	5.5	530	0	0	120	ND[b]	200	197	4/4	148
4	3/02/82	111	7.8	1.5	0.4	6.1	1,200	0	1	27	ND	300	0	1/5	36
9	3/03/82	90	7.9	1.7	1.4	6.7	63	0	0	0	ND	1700	0	3/3	0
10	3/03/82	116	7.9	1.7	1.5	6.7	63	0	0	0	ND	0	3	0/4	586
18	3/04/82	87	7.9	1.9	1.1	3.3	ND	0	ND	ND	ND	0	0	0/7	0
25	7/19/82	64	6.6	5.0	0.1	17.0	69	200	0	300	ND	100	0	0/4	930
30	7/20/82	37	6.4	0	0.1	3.4	82	1,280	0	720	ND	3100	0	2/3	5,904
55	1/25/83	12	7.6	0.6	0.4	5.5	100	12	0	2,100	3	0	0	0/5	0
56	1/25/83	48	7.6	0.6	0.4	5.5	100	12	0	2,100	3	0	2	0/5	0
66	1/26/83	127	8.0	0.8	0.6	4.4	138	2	0	> 300	30	0	0.8	0/5	0
67	1/26/83	48	7.6	0.7	0.5	3.2	83	9	0	450	16	0	0	0/5	0
68	1/26/83	93	7.7	0.8	0.7	4.0	120	9	0	960	19	0	0	5/5	0
78	1/27/83	92	8.0	0.6	0.5	2.8	51	0	0	> 300	ND	0	0	0/5	0
79	1/27/83	91	8.0	0.6	0.5	2.8	51	0	0	> 300	ND	0	1.0	0/5	482
80	1/27/83	76	7.7	0.6	0.1	3.2	110	0	0	670	11,000	400	4	0/5	95
85	1/28/83	85	7.6	0.5	0.2	3.0	140	12	0	1,550	ND	0	0	0/5	0

[a] Water sample plated directly on E. Coli Hfr host bacteria

[b] ND = Not determined

TABLE 3. PHYSICAL-CHEMICAL, BACTERIAL AND VIRAL QUALITY OF FILTERED WATER SAMPLES FROM A DRINKING WATER TREATMENT FACILITY

Sample No.	Date	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Total Plate Count/ml	Bacteria/100 ml: Total Coliforms	Fecal Coliforms	Fecal Strep	Entero-cocci	Viruses: Coliphage/ 1 L (Direct)[a]	Coliphage/ 1 L (Concentrate)	Enterovirus CPE #+/# Tested	Rota-virus/ 100 L
29	7/20/82	378	8.5	8.5	0.8	8.6	170	250	64	2,800	ND[b]	800	0.3	0/5	171
34	7/21/82	378	6.4	>10.0	0.1	1.5	100	3,000	0	2,000	ND	100	0	0/3	585
35	7/21/82	359	6.9	>10.0	0.1	10.0	43	300	0	10	ND	600	2	1/5	404
36	7/21/82	340	6.6	>10.0	1.0	6.5	620	46	0	160	ND	100	0	2/3	463
37	7/21/82	340	6.5	>10.0	0.6	7.8	43	42	0	30	ND	300	6	0/4	88
47	1/24/83	176	7.7	2.4	1.6	0.45	1	0	0	17	2	0	0	0/5	182
52	1/25/83	310	7.4	1.0	0.7	1.4	20	0	0	92	3	100	0	0/5	0
53	1/25/83	286	7.9	0.9	0.6	0.7	15	0	0	118	3	0	0	0/5	0
54	1/25/83	557	7.7	0.9	0.7	1.4	14	0	0	72	1	0	0.2	0/4	535
64	1/26/83	250	7.9	1.6	1.3	0.72	10	0	0	31	1	300	0	0/5	0
65	1/26/83	217	7.9	1.7	1.4	0.85	9	0	0	24	3	0	0	0/5	3,706
81	1/27/83	59	ND	1.8	1.0	1.1	8	0	0	40	ND	100	10	0/5	0
84	1/28/83	336	7.6	2.5	1.1	0.66	16	1	0	66	ND	0	0	0/5	0

[a] Water sample plated directly on E. Coli Hfr host bacteria

[b] ND = Not determined

TABLE 4. PHYSICAL-CHEMICAL, BACTERIAL AND VIRAL QUALITY OF FINISHED WATER SAMPLES FROM A DRINKING WATER TREATMENT FACILITY

Sample No.	Date	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Bacteria/100 mls: Total Plate Count/ml	Total Coliforms	Fecal Coliforms	Fecal Strep	Entero-cocci	Viruses: Coliphage/ 1 L (Direct)	Coliphage/ 1 L (Concentrate)[a]	Enterovirus CPE #+/# Tested	Rota-virus/ 100 L
1	3/02/82	525	6.8	7.5	1.0	0.73	21	0	0	1	ND[b]	0	0	5/5	233
2	3/02/82	756	6.8	6.5	1.0	0.84	110	0	0	27	ND	0	0.1	0/5	0
7	3/03/82	416	7.8	ND	0.75	0.64	16	0	0	16	ND	0	0	3/3	0
8	3/03/82	416	7.8	ND	0.75	0.64	16	0	0	16	ND	0	0	0/5	126
13	3/03/82	513	8.1	2.7	2.2	2.9	1	0	0	3	ND	0	0	3/3	0
14	3/03/82	549	8.1	2.7	2.0	2.9	ND	0	ND	ND	ND	ND	0	0/4	0
15	3/04/82	756	7.7	1.9	0.5	0.95	100	0	0	3	ND	0	0	0/5	0
16	3/04/82	626	7.9	2.6	2.5	0.65	ND	0	ND	ND	ND	0	0	4/4	0
17	3/04/82	691	7.9	2.5	2.1	0.65	ND	0	ND	ND	ND	ND	0	0/5	0
22	7/19/82	375	6.0	>10.0	1.1	8.6	> 200	> 2,000	0	640	ND	400	0	1/4	243
23	7/19/82	246	6.2	>10.0	1.2	15.0	> 200	> 2,000	0	1,152	ND	400	1	0/4	332
24	7/19/82	412	6.9	>10.0	0.5	6.0	53	70	10	540	ND	900	31	0/4	10,448
27	7/20/82	247	6.7	>10.0	0.8	15.0	> 200	> 2,000	ND	> 200	ND	600	0	0/5	57
28	7/20/82	268	6.8	>10.0	0.6	8.5	240	> 2,000	5	> 2,000	ND	400	0.4	0/3	248
32	7/21/82	378	6.7	>10.0	1.4	7.2	1,230	15,300	0	16,100	ND	1000	0	0/4	157
33	7/21/82	467	6.7	8.0	0.7	4.5	1,340	5,000	0	200	ND	200	0	0/3	459
38	7/22/82	378	6.8	6.5	0	13.0	ND	ND	ND	ND	ND	400	130	0/5	69
39	7/22/82	376	6.7	>10.0	0.4	8.9	ND	ND	ND	ND	ND	300	133	0/5	106
41	1/24/83	379	ND	3.0	1.5	1.0	34	0	0	30	0	0	0	0/5	0
42	1/24/83	870	ND	2.6	1.8	0.84	22	0	0	132	2	0	0	0/5	0
43	1/24/83	396	7.4	2.4	1.6	0.47	13	0	0	172	0	0	0	0/5	0
44	1/24/83	337	ND	2.5	1.5	ND	31	0	0	126	0	0	0	0/5	0
45	1/24/83	480	6.5	2.4	1.9	0.48	5	0	0	21	0	0	0	0/5	0
46	1/24/83	616	7.6	3.0	1.5	0.48	18	0	0	12	0	100	0.2	0/5	0
48	1/25/83	310	7.3	2.5	1.7	0.79	8	0	0	98	15	0	0	0/5	78
49	1/25/83	377	7.3	2.4	1.6	0.65	12	0	0	15	ND	0	0	0/3	0
50	1/25/83	708	7.3	2.6	1.6	0.68	13	0	0	34	1	0	0	1/5	0
51	1/25/83	378	7.6	2.2	2.0	0.56	15	0	0	45	2	100	0	0/5	0
59	1/26/83	167	6.9	2.4	1.7	0.66	4	0	0	33	1	0	0	0/5	0
60	1/26/83	221	7.0	1.9	1.6	0.45	6	0	0	210	108	0	0	0/5	0
61	1/26/83	374	6.9	2.3	1.7	0.94	6	0	0	610	1	0	0	0/5	0
62	1/26/83	763	7.7	2.6	2.0	0.6	7	0	0	40	2	0	0.5	0/5	0
63	1/26/83	380	7.9	2.9	2.4	1.2	14	0	0	43	2	0	0	0/2	0

[a] Water sample plated directly on E. Coli Hfr host bacteria

[b] ND = Not determined

continued

TABLE 4. (CONTINUED)

Sample No.	Date	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Total Plate Count/ml	Bacteria/100 mls: Total Coliforms	Fecal Coliforms	Fecal Strep	Entero-cocci	Viruses: Coliphage/ 1 L (Direct)	Coliphage/ 1 L (Concentrate)[a]	Enterovirus CPE #+/# Tested	Rota-virus/ 100 L
71	1/27/83	383	7.6	2.5	1.7	0.96	42	0	0	210	3	0	0	0/5	0
72	1/27/83	375	7.5	1.8	1.6	1.6	23	5	0	> 300	ND	0	0	0/5	0
73	1/27/83	380	7.6	2.5	1.5	0.8	76	0	0	188	ND	0	0	0/4	0
74	1/27/83	212	8.0	1.8	1.3	0.85	34	0	0	180	ND	0	0	0/5	60
75	1/27/83	313	7.8	2.4	1.5	0.77	8	1	0	139	780	0	0	0/5	0
76	1/27/83	528	7.8	2.4	1.5	0.77	8	1	0	139	780	0	0	0/5	0
77	1/27/83	358	7.8	2.4	1.5	0.77	8	1	0	139	780	0	0.6	0/5	0
83	1/28/83	123	7.7	1.5	1.0	0.99	2	0*[c]	0*	2	ND	0	0	0/5	0
90	4/07/83	453	8.2	9.0	1.7	0.89	8	0	0	9	ND	0	0.4	0/5	0
91	4/07/83	503	8.0	9.0	1.5	1.3	2	3	ND	0	ND	0	0	0/5	0
92	4/07/83	462	8.2	9.5	1.7	1.4	2	0	ND	0	ND	0	0	0/5	0
93	4/07/83	488	8.2	3.0	1.7	0.64	72	4	0	11	ND	0	0	0/5	0
94	4/07/83	467	8.2	2.0	1.7	1.5	2	0	0	0	ND	0	0	0/5	0
95	4/07/83	378	8.2	2.5	1.5	1.3	2	6	0	0	ND	0	0	0/5	0
96	4/07/83	472	8.2	2.0	1.6	0.83	4	0	0	0	ND	0	0	0/5	0
97	4/07/83	451	8.2	2.0	1.4	1.0	2	1	0	0	ND	0	0	0/5	45
98	4/07/83	484	8.5	2.5	1.5	1.0	1	0	0	6	ND	0	0	0/5	0
107	4/08/83	409	8.0	2.5	1.3	1.0	5	1*	0*	19*	ND	0	0	0/5	0
108	4/08/83	643	7.9	2.5	1.4	1.7	1	1*	0*	2*	ND	0	0	0/5	0
109	4/08/83	527	7.8	2.0	1.5	0.73	9	2*	1*	6*	ND	0	0	0/5	0
110	4/08/83	453	8.2	2.0	1.6	1.0	11	12*	1*	128*	ND	0	0	0/5	0
111	4/08/83	413	8.4	2.0	1.5	1.0	9	3*	0*	156*	ND	0	0	0/4	0
112	4/08/83	534	7.9	2.0	1.6	0.94	7	6*	0*	91*	ND	100	0	0/5	0
113	4/08/83	347	8.3	2.0	1.6	0.95	13	3	0*	40	ND	100	0	0/5	33
114	4/09/83	632	8.0	2.5	1.5	1.1	13	17*	ND	830	ND	0	0	0/5	0
115	4/09/83	490	ND[b]	2.0	1.5	ND	ND	ND	ND	ND	ND	0	0	0/2	7
116	4/09/83	607	7.9	2.3	1.7	1.6	25	31*	ND	10	ND	0	0	0/5	0
117	4/09/83	535	8.3	2.0	1.5	1.0	5	5*	1*	20	ND	0	0	0/5	0
118	4/09/83	424	8.1	2.3	1.7	1.3	17	10*	8*	10	ND	0	0	0/5	0
119	4/09/83	437	8.1	2.0	1.6	1.5	6	0*	0*	0*	ND	0	0.5	0/5	0

[a] Water sample plated directly on E. Coli Hfr host bacteria

[b] ND = Not determined

[c] * 200 ml volumes were sampled

TABLE 5. SUMMARY OF ENTERIC VIRUS ISOLATION

FROM ALL SAMPLES[a] AFTER SUCCESSIVE DRINKING WATER TREATMENT PROCESSES

Site	Raw		Clarified		Filtered		Finished		Samples meeting[b] standards	
Number of Samples Collected	19		14		8		54		33	
Virus	Number Positive	%	Number Positive	%	Number Positive	%	Number Positive	%	Number Positive	%
Enterovirus	9	47	4	29	0	0	5	9	4	12
Rotavirus	9	47	5	36	3	37	7	13	5	15
Both Entero & Rotaviruses[c]	5	26	2	10	0	0	1	2	1	3
TOTAL ENTERIC VIRUSES	13	68	7	50	3	37	11	20	8	24

[a] = All samples collected during the dry season only.

[b] = Number of finished water samples positive for virus which had free chlorine residual and met U.S. turbidity, and bacterial standards.

[c] = Number of samples positive for both Entero and Rotaviruses.

TABLE 6. SUMMARY OF MEAN RECOVERIES[a] FOR TURBIDITY, BACTERIA AND VIRUSES AFTER SUCCESSIVE DRINKING WATER TREATMENTS

Site	Date	Collection	Turb. NTU	Total Plate Count/ml	Bacteria/ 100 ml: Total Coliforms	Fecal Coliforms	Fecal Strep	Enterococci	Coliphage/ L (Direct)	Coliphage/ L (Concentrate)	Enterovirus[b] CPE	Rotavirus/ 100 L
Raw												
	3/82	1	6.4	240	600	203	2,436	ND[c]	700	417	80%	408
	1/83	3	3.4	864	70	6	15,205	1165	3300	1119	50%	0
	4/83	4	10.9	440	264	147	2,766	ND	1700	599	25%	14
	Means[d]		8.0	465	216	66	4,452	1165	1769	680	47%	15
Clarified												
	3/82	1	5.7	126	0	0	13	ND	500	4	60%	20
	1/83	3	3.8	94	4	0	1,120	31	100	1	11%	3
	Means		4.5	103	2	1	189	31	177	2	29%	6
Filtered												
	1/83	3	0.9	9	1	0	47	2	6	1	0%	12
	Means		0.9	9	1	0	47	2	6	1	0%	12
Finished												
	3/82	1	1.2	20	0	0	6	ND	0	0.8	44%	3
	1/83	3	0.8	12	1	0	67	6	1	0.9	4%	1
	4/83	4	1.1	6	3	1	8	ND	1	0.9	0%	1
	Means		1.0	9	1.5	1	20	6	1	0.9	9%	1

[a] = All bacterial and viral numbers are geometric means, turbidities are arithmetic means.

[b] = Percentage of samples positive for virus.

[c] = Not determined

[d] = weighted by number of samples/trip.

TABLE 7. AVERAGE TURBIDITY, COLIFORM BACTERIA,

FREE CHLORINE AND VIRUSES IN FINISHED WATER SAMPLES

Season	Date	Collection Period	# of Samples	Turbidity NTU	Total Coliform/ 100 ml	Free Chlorine mg/L	Coliphage/L (Direct)[a]	Enterovirus CPE[b]	Rota-virus/[a] 100 L
Dry	3/82	1	9	1.21	0	1.42	0	44%	3
	1/83	3	23	0.79	1.0	1.64	1	4%	1
	4/83	4	22	1.13	3.0	1.56	1	0%	1
Average				1.04	1.5	1.57	1	9%	1
Rainy	7/82	2	9	9.63	1750	0.74	450	11%	264

[a] = geometric means

[b] = percentage of samples positive for virus

TABLE 8. AVERAGE PERCENT REDUCTIONS OF TURBIDITY, BACTERIA AND VIRUSES AFTER SUCCESSIVE DRINKING WATER TREATMENTS

From Raw to Site	Date	Collection	Turb. NTU	Total Plate Count	Bacteria				Coliphage (Direct)	Coliphage (Concentrate)	Entero-virus CPE	Rota-virus
					Total Coliforms	Fecal Coliforms	Fecal Strep	Entero-cocci				
Prechlorinated/ Clarified	3/82	1	11	47.5	100.0	99.5	99.5	ND[b]	28.5	99.0	25	95
	1/83	3	0[a]	89.1	94.3	100	92.6	97.3	97.0	99.91	78	0
Grand Mean[c]			4	78.9	98.9	97.1	97.2	97.3	90.4	99.7	55	61
Filtered	1/83	3	73	98.9	98.5	100	99.7	99.8	99.8	99.9	100	0
Finished	3/82	1	81	91.7	100	100	99.7	ND	100	99.8	45	99
	1/83	3	76	98.6	98.6	100	99.5	99.5	99.9	99.9	92	0
	4/83	4	90	98.6	98.9	99.3	99.7	ND	99.9	99.8	100	93
Grand Mean			87	98.1	99.3	98.5	99.5	99.5	99.9	99.9	81	93

[a] = No removal

[b] = not determined

[c] = mean reductions determined using mean counts weighted by number of samples per trip

TABLE 9. CHARACTERISTICS OF FINISHED DRINKING WATER SAMPLES WITH EXTENDED CHLORINE CONTACT TIME

Sample No.	Extended Chlorine Contact time[a]	Vol. (L)	pH	Total Chlorine mg/L		Free Chlorine mg/L		Turb. NTU	Bacteria/100 ml: Total Plate Count/ml	Bacteria/100 ml: Total Coliforms	Bacteria/100 ml: Fecal Coliforms	Bacteria/100 ml: Fecal Strep	Coliphage/L (Direct)	Coliphage/L (Concentrate)	Enterovirus Cultures CPE #+/# Tested	Rotavirus/100 L
A[b]	0	450	8.1	4.6		1.6		1.1	17	4	1.6	5	0	0.06	0	7.5[c]
92	30	503	8.2	9.5[d]	8.5[e]	1.7[d]	1.4[e]	1.4	2	0	ND[f]	0	0	0	0/5	0
94	30	467	8.2	2.0	2.5	1.7	1.5	1.5	2	0	0	0	0	0	0/5	0
96	30	472	8.2	2.0	2.0	1.6	1.5	0.83	4	0	0	0	0	0	0/5	0
98	30	484	8.5	2.5	2.5	1.5	1.6	1.0	1	0	0	6	0	0	0/5	0
117	60	535	8.3	2.0	2.0	1.5	1.2	1.0	4	5*	1.5*	20	0	0	0/5	0
119	60	437	8.1	2.0	1.5	1.6	1.2	1.5	6	0*	0*	0	0	0	0/5	0

[a] = Minutes past the assumed contact time of 30 minutes within the plant

[b] = Average of six samples; 90, 91, 93, 95, 97 and 118 (4/83)

[c] = Only one sample positive for rotavirus

[d] = Beginning chlorine

[e] = Ending chlorine

[f] = ND - Not Determined

* = 200 ml volumes were sampled

TABLE 10. HOURLY FLUCTUATIONS OF WATER QUALITY IN RAW AND FINISHED WATER AT A DRINKING WATER TREATMENT FACILITY

Site	Sample No.	Time	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Total Plate Count/ml	Bacteria / 100 ml			Viruses			
								Total Coliforms	Fecal Coliforms	Fecal Strep	Coliphage/ L (Direct)	Coliphage/ L (Concentrate)	Enterovirus Cultures CPE #+/# Tested	Rota-virus/ 100 L
Raw	100	9:30	8.2	0	0	8.9	263	420	390	300	2200	2800	0/5	0
	101	10:30	8.1	0	0	6.3	273	480	280	800	1800	1085	0/5	0
	102	11:30	8.2	0	0	11.0	480	460	180	1,300	2000	821	0/5	203
	103	12:30	8.1	0	0	25.0	420	420	140	3,500	1800	1256	0/5	0
	104	1:30	8.2	0	0	11.0	660	210	60	9,100	1800	464	1/4	166
	105	2:30	8.2	0	0	10.0	560	80	80	12,000	2000	259	0/5	592
	106	3:30	8.3	0	0	6.3	510	40	170	7,200	1200	103	0/5	97
Finished														
	107	9:30	8.0	2.5	1.3	1.0	5	1*	0*	19	0	0	0/5	0
	108	10:30	7.9	2.5	1.4	1.7	12	1*	0*	2*	0	0	0/5	0
	109	11:30	7.8	2.0	1.5	0.73	11	2*	1*	6*	0	0	0/5	0
	110	12:30	8.2	2.0	1.6	1.0	9	12*	1*	128*	0	0	0/5	0
	111	1:30	8.4	2.0	1.5	1.0	11	3*	0*	156*	0	0	0/5	0
	112	2:30	7.9	2.0	1.6	0.94	9	6*	0*	91*	100	0	0/5	0
	113	3:30	8.3	2.0	1.6	0.95	7	3*	0*	40*	100	0	0/5	33

[a] = 4/83

* = 200 ml volume samples

TABLE 11. ENTEROVIRUS DETECTION AND IDENTIFICATION FROM SAMPLES AT A DRINKING WATER TREATMENT FACILITY

Site	Sample No.	Isolate Number	Date	1st Passage[a]	2nd Passage[a]	Plaqued[b]	3rd Passage[a]	TEM[c]	ID[d]
Raw	5	1	3/2/82	+	+	+			Coxsackie B5
	6	1	3/2/82	+	+	+			Polio-1
		2		+	+	+			CB-5
		3		+	+	+			Polio-1
	11	1	3/3/82	+	+	+			CB-5
		2		+	+	+			CB-5
		3		+	+	+			CB-5
	19	1	3/4/82	+	+	+			Echo-24
		2		+	+	+			Echo-24
	26	1	7/19/82	+	+	+			CB-5
	57	1	1/25/83	+	+	-	-	+	Unk[e]
		2		+	+	-	-	+	Unk
	58	1	1/25/83	+	+	-	-	+	Unk
	69	1	1/26/83	+	+	+			Echo 9
		2		+	+	+			Echo 9
		3		+	+	+			Echo 9
		4		+	+	+			Echo 9
	99	2	4/7/83	+	+	-	+	-	Unk
		4		+	+	-	+	+	Unk
	104	1	4/8/83	+	+	-	+	+	Unk
Clarified	3	1	3/2/82	+	+	+			Echo 9
		2		+	+	+			Echo 9
		3		+	+	+			Echo 9
		4		+	+	+			U[f]
	4	1	3/2/82	+	+	+			Polio-1
	9	1	3/3/82	+	+	+			U
		2		+	+	+			U
		3		+	+	+			U
	30	1	7/20/82	+	+	-	-	+	Unk
		2		+	+	-	-	+	Unk
	68	1	1/26/83	+	+	-	+	+	Unk
		2		+	+	-	+	+	Unk
		4		+	+	-	+	-	Unk
		5		+	+	-	+	+	Unk
Filtered	35	1	7/21/82	+	+	-	-	+	Unk
	36	1	7/21/82	+	+	-	-	+	Unk
		2		+	+	-	-	+	Unk
Finished	1	1	3/2/82	+	+	+			CB-6
		2		+	+	+			CB-6
		3		+	+	+			CB-6
		4		+	+	+			CB-6
	7	1	3/3/82	+	+	+			U
		2		+	+	+			CB-5
		3		+	+	+			CB-5
	13	1	3/3/82	+	+	+			CB-5
		2		+	+	+			U
		3		+	+	+			CB-5
	16	1	3/4/82	+	+	+			Polio-1
		2		+	+	+			Polio-1
		3		+	+	-	-	+	Unk
		4		+	+	-	-	+	Unk
	22	1	7/19/82	+	+	-	-	+	Unk
	50	1	1/25/83	+	+	-	+	+	Unk

[a] CPE produced on a monolayer of BGM cells

[b] Agar-overlay technique on BGM cells

[c] Transmission electron microscopy

[d] Identified by serum neutralization using Lim-Melnick Antibody Serum pools

[e] Unknown, did not plaque

[f] Unidentifiable with antibody pools

TABLE 12. CORRELATION COEFFICIENTS FOR PHYSIO-CHEMICAL, BACTERIOLOGICAL AND VIROLOGICAL VARIABLES FROM RAW, CLARIFIED AND FILTERED WATER SAMPLES[a]

	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Total Plate Count	Total Coliforms	Fecal Coliforms	Fecal Strep	Coliphage/ Direct	Coliphage/ Concentrate	Entero-virus (+/-)	Rota-virus (+/-)	Rota-virus (# s)
Vol. (L)	1.00	-.12	.40	.24	-.40	-.51	-.39	-.22	-.35	-.31	-.37	-0.34	.17	.14
pH		1.00	-.71	-.02	-.20	.09	-.01	.35	.00	.31	.42	.17	-.07	-.10
Total Chlorine mg/L			1.00	.24	-.05	-.30	-.16	-.22	-.31	-.28	-.50	-.20	.30	.28
Free Chlorine mg/L				1.00	-.32	-.41	-.49	-.41	-.53	-.46	-.55	-.22	-.07	-.05
Turbidity NTU					1.00	.64	.73	.38	.49	.48	.52	.06	.12	.17
Total Plate Count						1.00	.70	.51	.74	.70	.79	.36	.01	-.02
Total Coliforms							1.00	.76	.74	.60	.69	.18	.04	.12
Fecal Coliforms								1.00	.55	.64	.66	.30	.14	.18
Fecal Strep									1.00	.56	.65	.17	-.10	-.07
Coliphage/Direct										1.00	.82	.32	-.04	-.04
Coliphage/Concentrate											1.00	.33	.03	.05
Enterovirus (+/-)												1.00	.05	.04
Rotavirus (+/-)													1.00	.96

[a] 36 samples with complete data, underlined values significant at .05 level

TABLE 13. CORRELATION COEFFICIENTS FOR PHYSIO-CHEMICAL, BACTERIOLOGICAL AND VIROLOGICAL VARIABLES FROM FINISHED WATER SAMPLES[a]

	Vol. (L)	pH	Total Chlorine mg/L	Free Chlorine mg/L	Turb. NTU	Total Plate Count	Total Coliforms	Fecal Coliforms	Fecal Strep	Coliphage/ Direct	Coliphage/ Concentrate	Entero-virus (+/-)	Rota-virus (+/-)	Rota-virus (# s)	Total Enteric (+/-)
Vol. (L)	1.00	.01	.29	-.01	.07	.18	.05	.19	-.19	.03	.26	.29	-.16	-.12	.01
pH		1.00	-.34	.24	-.01	-.43	-.07	.11	-.26	-.31	.11	-.17	-.13	-.23	-.12
Total Chlorine mg/L			1.00	-.41	.33	.44	.33	-.05	-.06	.49	.17	.24	.29	.41	.24
Free Chlorine mg/L				1.00	-.22	-.35	-.39	-.02	.04	-.43	.15	.01	-.39	-.46	-.23
Turbidity NTU					1.00	.16	.72	-.07	-.02	.79	-.07	.16	.25	.37	.36
Total Plate Count						1.00	.36	.10	.46	.41	-.07	-.06	.19	.27	.08
Total Coliforms							1.00	.12	.22	.85	-.13	-.12	.28	.40	.20
Fecal Coliforms								1.00	-.22	-.04	-.09	-.08	-.12	-.11	-.14
Fecal Strep									1.00	.18	-.01	-.20	-.13	-.11	-.16
Coliphage/Direct										1.00	-.05	-.04	.38	.53	.32
Coliphage/Concentrate											1.00	-.09	-.13	-.12	-.15
Enterovirus (+/-)												1.00	.15	.19	
Rotavirus (+/-)													1.00	.97	
Rotavirus (# s)														1.00	

[a] 41 samples with complete data, underlined values significant at .05 level.

TABLE 14. MULTIVARIATE LINEAR REGRESSION ANALYSIS (R^2 VALUES) FOR ENTERO AND ROTAVIRUSES

Predictive Models	Enterovirus (+/-)		Rotavirus (+/-)		Rotavirus (#s)	Total Enteric Viruses (+/-)
	Raw[a] Water Samples	Finished[b] Water Samples	Raw[a] Water Samples	Finished[b] Water Samples	Finished[b] Water Samples	Finished[b] Water Samples
1. Variables 1-11[e]	.3265	.3900	.3217	.3480	.4766[c]	.2922
2. Variables 1-5[e]	.1622	.1534	.2132	.2409	ND[d]	.1906
3. Variables 6-9[e]	.2232[c]	.0681	.0703	.2254	ND	.2063
4. Variables 6-10[e]	.2232	.0706	.0960	.2247	.3875[c]	.2101

[a] 36 samples

[b] 41 samples

[c] Significant at the 95% confidence limits

[d] ND=Not Determined

[e] Variables:

1. Volume
2. pH
3. Total chlorine
4. Free chlorine
5. Turbidity
6. Total plate count bacteria
7. Total coliform bacteria
8. Fecal coliform bacteria
9. Fecal streptococci bacteria
10. Coliphage (direct)
11. Coliphage (concentrate)

TABLE 15. COMPARATIVE REDUCTION OF TURBIDITY AND MICROORGANISMS BY DRINKING WATER TREATMENT PROCESSES

Parameter	Stetler et al. (1984) Percent Removal			Guadalajara Percent Removal		
	Clarified	Filtered	Finished	Clarified	Filtered	Finished
Turbidity	•70	90	96	40	73	87
Coliforms	90	98	>99.99	98.9	98.5	99.3
Fecal coliforms	91	91	>99.87	97.1	98.6	98.5
Fecal Strep	90	97.3	>99.95	97.2	99.7	99.5
Total Plate Count	70	90	>99.97	78.9	98.9	98.1
Enterovirus	61	90	>98	55	62	81
Rotavirus	ND[a]	ND	ND	61	0	93

[a]ND = Not determined